The Potential Incidence of Green Roofs on Urban Runoff Quality

Martin Seidl, Cécile Mirande-Bret, Mohammed Saad, Marie-Christine Gromaire

The Potential Incidence of Green Roofs on Urban Runoff Quality

Martin SEIDL*, Cécile MIRANDE, Mohamed SAAD, Marie Christine GROMAIRE

Université Paris-Est, LEESU ENPC
6-8 Avenue Blaise Pascal, Champs-sur-Marne, 77455 Marne-la-Vallée cedex 2, France
**Corresponding author*
Email: martin.seidl@leesu.enpc.fr

ABSTRACT

The article presents the results of one year of study on a set of pilot green roofs. The roofs were monitored for outflow and water quality of the runoff. The flux data of green roofs were compared to the reference roof consisting of bituminous membrane. The results show similar findings as the literature data, slight release of solids and nutrients. However, the metals can be retained (Zn) or released (Cu, Ni). Atmospheric pollutants like PAH are strongly retained, but on the other side plasticiser from green roof structure can be released. If the obtained data are applied to an urban area of known composition, the substitution of all roofs by green roofs, leads to slight (+19%) increase in the oxydable matter, but significant increase (+60%) in phosphorus loads to the receiving environment. There might be a pseudo effect on heavy metals discharge, but this is rather due to replacement of metallic parts than to roof impact itself. If we consider the real possibilities of roof greening (less than 15% of the total roof surface in Paris) these effects become minimal.

KEYWORDS

Green roof, runoff, storm water, pollutant loads, nutrients, trace metals, organic micro-pollutants, release, retention

INTRODUCTION

Green roofs may induce many benefits as well at the building scale (thermal and acoustical comfort of the building) as at the city scale (reduction of urban runoff, mitigation of city climate, landscape aesthetics (Wong et al., 2003; Rowe, 2010, Susca et al. 2011). However there is less consensus among the authors about other ecosystemic services like retention of pollutants from atmospheric fallout or carbon sequestration. Several short studies on run-off quality report different degrees of nutrients release and trace metal mobility (Hunt et al., 2006; Teemusk and Mander, 2007, Czermiel-Berndtsson, 2010, Beck et al., 2011, Seidl et al 2013), but rare are those worked out over long periods or handling organic pollutants.

The present paper discusses the incidence of vegetated roofs on the concentration and loads of roof runoff at the building scale (SS, COD, nutrients, PAH, metals), and the potential consequences of an extended roof greening on stormwater pollutant loads at the catchment scale. It is based on a one year follow up of (micro)pollutant concentrations and from an experimental green roofs in the suburbs of Paris.

METHODOLOGY

Experimental method

Green roofs setup The experimental roofs are situated in Trappes, a small city 30 km South-West from the centre of Paris. An existing 300 m² flat roof was transformed into 6 green stripes (35 m², 7x5 m) and 2 reference surfaces (21m², 7x3 m). In order to test effects of the green roof composition on the quantity and the quality of runoff water, different types of plants, substrates, substrate depths and drainage layers were tested (Gromaire et al 2013).

Each green roof consists of a substrate layer (mixtures of natural pumice, lava, bark compost and green compost), covered with a mix of sedums and equipped with geotextile and a drainage layer of expanded polystyrene or lava stone. The green roof used for comparison (code: SE3Y) consist of 3 cm intensive substrate and expanded polystyrene drainage layer on a SBS membrane.

The two reference roofs are representative of standard flat roofs. The first one (code: BI) is a SBS elastomeric bitumen waterproofing membrane, protected by slate chippings. The second one, has the same composition but is covered by 5 cm of gravel.

The rainfall is measured with a rain gauge located on the roof, having a resolution of 0.1 mm. The run-off from each roof compartment is measured continuously at the outlet with a specially constructed tipping buckets flow meter, to get a resolution of 0.01 mm rainfall.

The water samples are collected at the issue of the flow metering. On one side of the tipping bucket the sampling line, is entirely made of plastic components (PVC, PE, PTFE) and a 30 L plastic recipient to collect water for the analysis of heavy metals and global parameters. On the other side, the sampling line is entirely made of aluminum and PTFE and a 20 L glass recipient, to collect water for the analysis of organic contaminants. Both sampling line include a 10% diverter.

The water quality sampling set-up was completed by two rectangular funnels of 1 m² for collection and analysis of total atmospheric fall out. One, made of stainless steel was for the organic pollutants sampling and the other, made of polyethylene was for other parameters.

Sampling campaign During 2012 a thirteen rain events have been analyzed, monitoring in detail the hydraulic fluxes and using whole event samplers for the chemical composition.

Table 1: Characteristics of the 13 rain events collected for the water quality analysis between 6/1/12 and 5/12/12

Sampling date	Rain depth (mm)	Number of previous dry days (d)	Max. intensity over 3 min (mm/h)	Run-off coefficient	
				BI	SE3Y
median	10,20	1,06	12,00	0,79	0,65
standard deviation	5,76	4,88	15,99	0,13	0,28
min	2,90	0,13	4,00	0,41	0,10
max	21,10	15,06	52,00	0,90	0,88

Analytical methods The parameters followed can be divided in three pollutant groups: the global ones (S.S., nutrients etc.), the metals (copper, zinc etc.) and the organic pollutants (PAH, alkylphenols, etc.).

APHA and AWWA standards were applied for the treatment and analysis of all samples. Anions and cations were analyzed by ion chromatography on defrozen samples. Dissolved heavy metals (0,4 µm PTFE filters) were analyzed after HNO3 acidification by optic inducted coupled plasma (ICP), whereby total metal contents were determined after HNO3 / HCl / H2O2 extraction. Dissolved organic pollutants were analyzed after filtration (Whatman GF/F), extraction and separation on OASIS HLB (Waters) or C18 (Macherey Nage) cartridges using chromatography coupled with tandem mass spectrometry (GC-MS/MS or UPLC-MS/MS). The PAH and NP content in the solid phase were analyzed after microwave extraction on particulate matter retained on a oven cleaned Whatman GF/F filter.

In a first step, the concentrations and fluxes of the experimental green roof (SE3Y) were compared to those of the conventional flat roof (Bi).

Estimating the incidence of an extended roof greening at catchment scale

To estimate the potential impact of the large application of green roofs in an urban area on the storm water load, data of an existing urban area were combined with the experimental (green) roof data.

The annual pollutant load of an existing urban area can be estimated using the event mean concentrations of run-off during rain events, the surface ratio and the run-off coefficient of each specific surface (equation 1). The pollutant flux of a greened urban area can than be recalculated using different values for the roof compartment.

$$\mathbf{\Phi = h \sum C_{(i)} * A_{(i)} / A_{(t)} * k_{(i)}} \quad \text{with} \quad \mathbf{\sum A_{(i)} = A_{(t)}} \quad \text{or} \mathbf{\sum A_{(i)} / A_{(t)} = 1} \qquad \mathbf{(1)}$$

Φ : total pollutant flux generated by the urban area in [g/m²/year]
h : annual precipitation in [m]
C(i) : median, event mean concentration of surface type (i) in [mg/l]
A(i) : surface area of surface (i) in [m²]
A(t) : total area in [m²]
k(i) : average run-off coefficient of surface type (i)

The "Marais" catchment, 41 ha situated in the centre of Paris, was chosen as case study for the evaluation of an hypothetical roof greening scenario This catchment has been extensively studied in the past (Gromaire et al. 1999, Kafi et al., 2008). It can be divided into three main categories of urban surfaces : roofs, pavements and other surfaces (yards and gardens) accounting for 54%, 23% and 23% respectively (Gromaire et al, 1999). More characteristics are given in the table 2 below.

Average runoff concentrations for roofs, pavements and other surfaces on Marais catchment are given by Gromaire et al. (1999) for SS, COD, Cu and Zn. For N-tot and P-tot, which were not documented in Marais studies, average values were drawn from different literature data

For organic micropolluant, data on average runoff concentration levels per type of urban surface are very scarce. Thus, the calculation was completed with stormwater data, measured at the outlet of different stormsewers in Paris conurbation (Zgheib et al 2012, Gasperi et al in press 2014). In this case the total flux of the urban area can be describe by equation 2

$$\mathbf{\Phi = h * C_{(global)} * k_{(global)}} \quad \text{where } \mathbf{k_{(global)} = \sum k_{(i)} * A_{(i)}/A_{(t)}} \qquad \mathbf{(2)}$$

C(global) : average storm water concentration
k(global) : weighted run-off coefficient for the urban area considered,

If we assume that the contribution of waste water bypasses and releases from in-sewer sediments are negligible and that the existing roofs can be simulated by the experimental reference roofs. The flux of the hypothetic urban area can than be estimated from the global flux by substituting the contribution of existing roofs by green ones (equation 3):

$$\Phi = h^*\{C_{(global)}{}^* \, k_{(global)} \; - A_{(i)}/A_{(t)}{}^*\big(k_{(ref)} * C_{(ref)} \; + k_{(green)}{}^* \, C_{(green)}\big)\} \qquad (3)$$

C(ref) : median, event mean concentration of reference roof Bi in [mg/l]
C(green) : median, event mean concentration of reference roof SE3Y in [mg/l]

Both approaches are simplifications, but should lead to the same order of magnitude for the total urban load. The total flux calculated with the second method can be significantly superior to the one given by equation (1) as stormwater concentrations at catchment outlet are influenced by in sewer processes and cross contaminations due to faulty connections and waste water bypasses (Bressy et al 2012).

RESULTS & DISCUSSION

The studied green roof acts as a source of solids and carbon, of phosphorus and in some extend of nitrogen. This results are in accordance with previous research (Hunt et al., 2006; Teemusk and Mander, 2007, Czermiel-Berndtsson, 2010, Beck et al., 2011, Seidl et al 2013). This release trend is followed by major metals like iron and manganese. However some trace metals like zinc and in less extend copper are retained (Figure 1). The organic micro-pollutants give a more nuanced picture. Some, like PAH originating principally from atmospheric fallout are retained while others, like nonylphenol contained in the roof components are released.

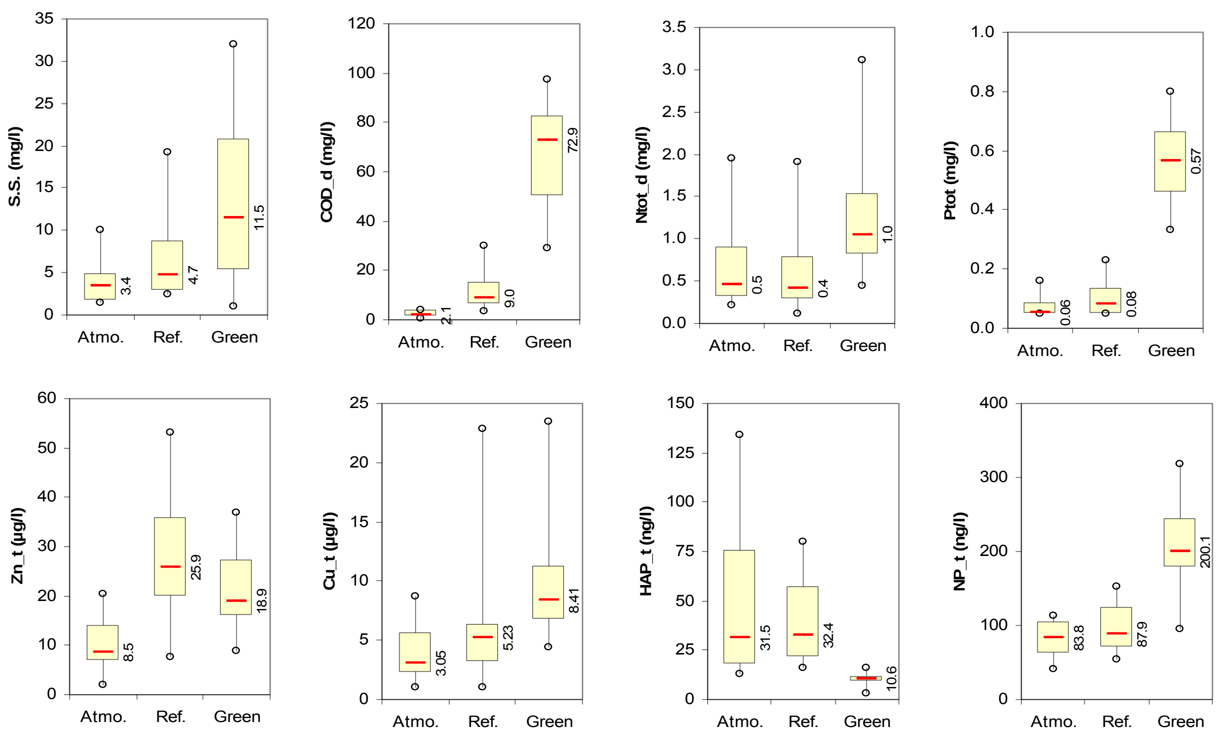


Figure 1: distribution of runoff concentrations measured for atmospheric fallout (RA),

bitumen reference roof (BI) and vegetated roof (SE3Y). The box plots indicate median, Q25-Q75 and minimum - maximum values.

To take into account the difference in run-off coefficients between the two experimental surfaces, pollutant loads per rain event were calculated for both roofs. These fluxes were compared in the form of ratio of green roofs (SE3Y) over conventional roof (Bi). According to the flux ratio we can than distinguish three zones (Figure 2): up to 0.9 - retention, between 0.9 and 1.1 - no change, and above 1.1 - release.

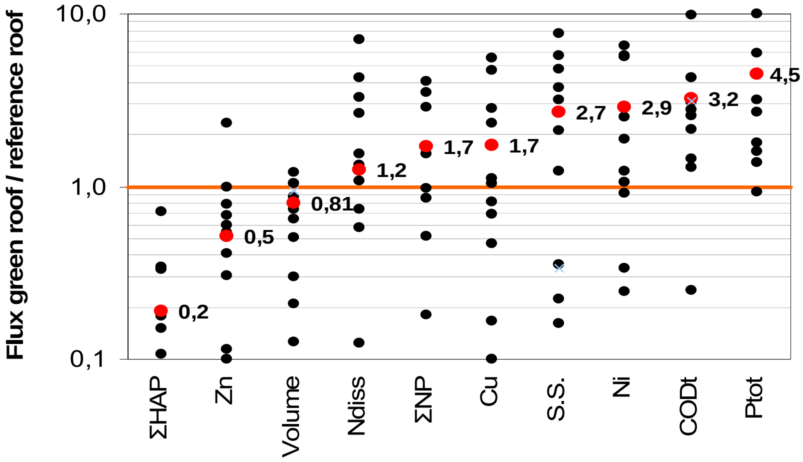


Figure 2: Release and retention behavior of selected pollutants, expressed as quotient of green roof flux and reference roof flux. Red point represents the average for all rains sampled, black points the individual events.

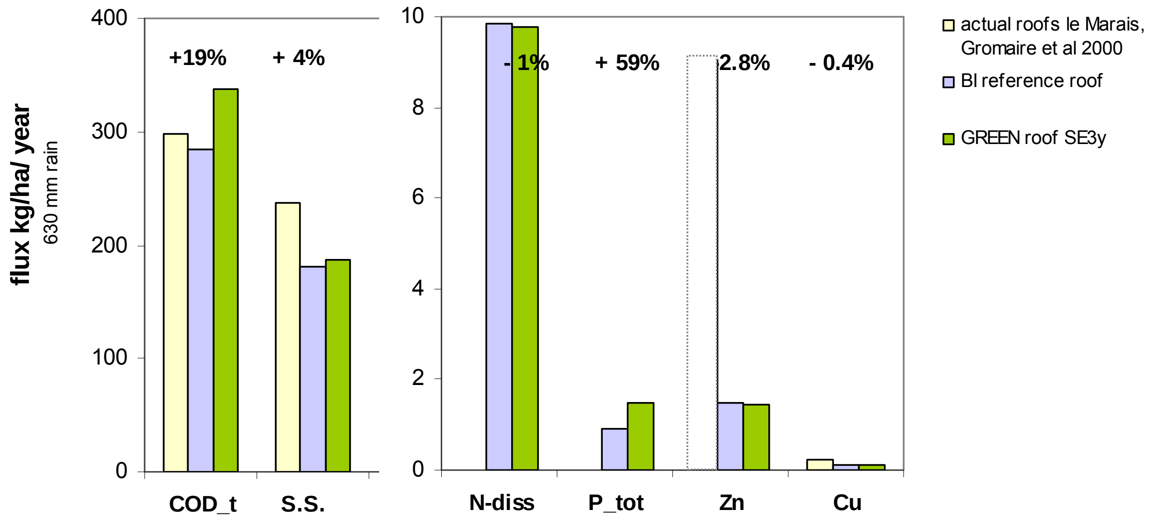
Incidence of green roofing at catchment scale

Table 2: Surface specification used for the global flux estimation. Mean concentration of the Marais area (*) (Gromaire et al., 1999 (**) Zheib et al 2012

surfaces	% total surface A(i) /A	run-off coef k(i)	COD_t mg/l	S.S. mg/l	N-diss mg/l	P_tot mg/l	Zn µg/l	Cu µg/l
actual roofs Paris (*)	54,5%	0,9	31	29	n.a.	n.a.	2305	37
conventional reference roof ,(BI)	54,5%	0,9	20,9	4,7	0,7	0,08	29,6	5,5
green roof, (SE3Y)	54,5%	0,5	78,7	11,5	1,2	0,57	21,3	9,5
pavement (*)	23%	0,8	131	92,5	<u>5</u>	<u>0,45</u>	813	61
others (*)	22,5%	0,2	95	74	<u>3</u>	<u>0,27</u>	693	23
storm waters (**)	100%		89	106			270	55

continuation	**PAH ng/l**	**NP ng/l**
storm waters (**)	1327	750

The above data were used to evaluate for a given urbanized area the possible effect of the substitution of conventional roofs by green ones. If we take as example an urban tissue like Paris with 54,5%of the urbanized surface covered by roofs, 23% by pavement and 22,5%by other types of surface (table 2), each with its specific run off coefficient, and the replacement of all roof by green roof cover, we obtain figure 2. The results show only a substantial increase in runoff load for COD and phosphorus. For the other contaminants, greening roof does not induce any significant variation in storm water loads at catchment scale, even under the very excessive hypothesis that all roofs are replaced with green roofs. The main source of



these contaminants is linked to road surfaces or to the use of metals in materials for runoff collection. In the Marais this last point is particularly true for Zn, as half of the actual roof surface is covered with zinc and as most of the downspout rain pipes are made of zinked tubes (transparent Zn-bar in figure 3)

Figure 3: Pollutant fluxes from an urban tissue of Paris, before and after substitution of all roofs by experimental reference and green roofs.

To confirm the above estimation and to get also some indication about the organic micro pollutants effect of the greening, an estimation of the impact is also made from storm water data. The results of this estimation (figure 4) are similar to the first method (figure 3), no or little impact at the city scale. Thought the impact might be underestimated if the data come from areas with urbanization being equipped with metal rain tubing, important metallic urban (infra)structures or suffering from much higher atmospheric fallout than the experimental green roof site.

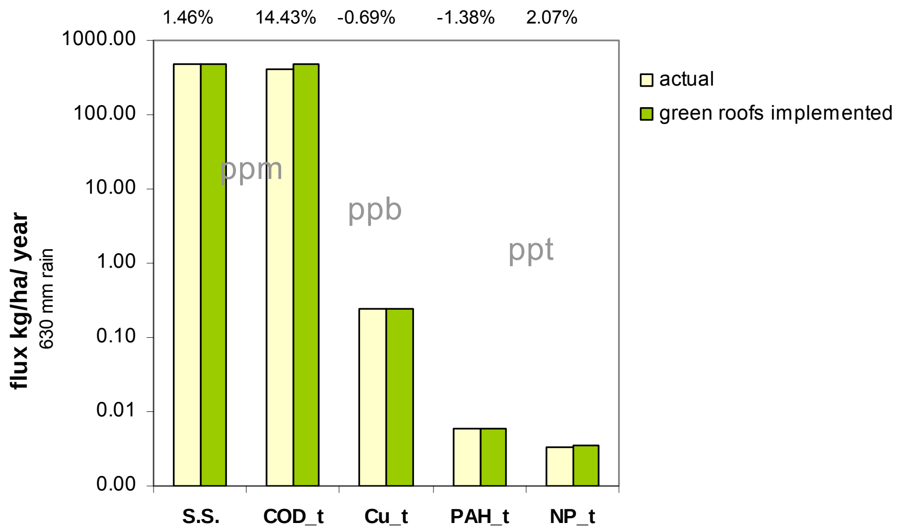


Figure 4: Pollutant fluxes from urban tissue of Paris, using storm-water concentration. All conventional roofs were replaced by green ones. The grey letters indicate the level of contaminant.

CONCLUSIONS

The behavior of vegetated roofs towards contamination depends on the characteristics of the considered pollutant like origin and molecular properties. The emitted contaminant loads are dependant of the hydrologic behavior of the roof and thus on soil moisture and rain depth.

At urban scale the green roof may increase the COD and the P load towards the receiving systems. The simulation made for total replacement of conventional roof is however far above the real possibilities and though the contribution of the green roofs to the total pollutant load, generated by urban area will be negligible. For example in Paris only 1,2% of roof surfaces are actually vegetated and 12,5% of roofs could be vegetated (APUR 2013) So in practice application of green roofs on all potentially available surface in Paris will not significantly change the urban pollutant flux of any parameter studied.

Nevertheless in case of receiving ecosystems sensitive to eutrophication the management of green roof surfaces should be planned and managed carefully.

REFERENCES

APUR (2013) Étude sur le potentiel de végétalisation des toitures terrasses à Paris. avril 2013 39 pages Cote : AP BROAPU606

Berndtsson J. C. (2010). Green roof performance towards management of runoff water quantity and quality: A review. Ecological Engineering 36(4): 351-360.

Bressy Adèle; Marie-Christine Gromaire; C. Lorgeoux; M. Saad; F. Leroy; G. Chebbo (2012) Towards the determination of an optimal scale for stormwater quality management: Micropollutants in a small residential catchment.Water Research, 2012, 46 (20), pp. 6799-810

Gromaire Marie Christine; David Ramier, Martin Seidl ; Emmanuel Berthier, Mohamed Saad, Bernard de Gouvello (2013) Impact of extensive green roofs on the quantity and the quality of runoff – first results of a test bench in the Paris region Conference NOVATECH 2013 Lyon France

Gromaire-Mertz, M.C., Garnaud, S., Gonzalez, A., Chebbo, G., 1999. Characterisation of urban runoff pollution in Paris. Water Science and Technology, Innovative Technologies in Urban Storm Drainage 1998 (Novatech '98) Selected Proceedings of the 3rd NOVATECH Conference on Innovative Technologies in Urban Storm Drainage 39, 1–8. doi:10.1016/S0273-1223(99)00002-5

Hathaway A. M., Hunt W. F., Jennings G. D. (2008). Afield study of green roof hydrologic and water quality performance. Transactions of the Asabe 51(1): 37-44.

Hunt, W., Hathaway, A., Smith, J., Calabria, J., (2006). Choosing the right green roof media for water quality. In: Proceedings of the Greening Rooftops for Sustainable Communities, Boston, MA 2006.

Kafi, M., Gasperi, J., Moilleron, R., Gromaire, M.C., Chebbo, G., 2008. Spatial variability of the characteristics of combined wet weather pollutant loads in Paris. Water Research 42, 539–549. doi:10.1016/j.watres.2007.08.008

Rowe D. B. (2011). Green roofs as a means of pollution abatement. Environmental Pollution 159(8-9): 2100-2110.

Seidl M., Gromaire M.C., Saad M. and De Gouvello B. (2013). Effect of substrate depth and rain-event history on the pollutant abatement of green roofs, Environmental Pollution 183: 195-203.

Susca, T.; S.R. Gaffin, G.R. Dell'Osso, (2011) Positive effects of vegetation: Urban heat island and green roofs, Environmental Pollution, Volume 159, Issues 8–9, August–September 2011, Pages 2119-2126, ISSN 10.1016/j.envpol.2011.03.007.

Teemusk A., Mander U. (2011). The Influence of Green Roofs on Runoff Water Quality: A Case Study from Estonia. Water Resources Management 25(14): 3699-3713.

Zgheib, S., Moilleron, R., Chebbo, G., 2012. Priority pollutants in urban stormwater: Part 1 – Case of separate storm sewers. Water Research 46, 6683–6692. doi:10.1016/j.watres.2011.12.012